AGROFORESTRY AS A METHOD OF DRAINAGE WATER REUSE

A Review of Literature

Agroforestry, has been defined by Cervinka (1999) as, "the practice of growing certain types of trees with drainage water. The trees act to dispose of applied drainage and shallow groundwater through foliar evaporation and at that time produce a marketable commodity". Since most of the review information is for the purpose of drainage water reuse in the San Joaquin Valley of California and Cervinka has been one of the primary proponents of agroforestry in that area, it is his definition that will be used in this discussion.

Many have planted non-native exotic trees in various locations in California going back even to the original Spanish settlers in the late 18th century. One of the modern experiments with trees in California soils with high levels of salinity may have been in the Napa Valley starting in 1972. (Donaldson et al., 1983) Here fifty-five eucalyptus species were planted, of which only 26 remained after eight years in saline, flooded soils. See Table 3 later in this report, for the listing of the twenty-six species. Fifty-one other tree species were planted only three of which survived and even these were deemed, "surviving but not acceptable" when judged in May 1982. One interesting note in the presentation is a caption for a picture: "Many trees on the salty plain seemed to thrive for six or more years before succumbing. This may be an individual trait, not species failure, since others of the same species survive and are highly acceptable. *Eucalyptus sargentii* (above) adjacent to the dying *Eucalyptus camaldulensis* (left) continues to grow as a superior specimen."

Eucalyptus camaldulensis, river red gum, was the predominant species for which agroforestry had been proposed for the use of saline drainage water in the San Joaquin Valley (SJV) of California. Since this species originated in Australia, it might be worthwhile to review information as it may relate to salinity problems on that continent. The July 2000, National Geographic picture on pages 6 and 7 is titled, A graveyard of skeletons with gray arms raised in good-bye" (Parfit and Wolinsky, 2000). In predominantly gray blue colors it portrays dead trees and their reflections in a shimmering lake. You can almost feel the sadness in looking at bare trees without life. The caption of the picture reads, Once a leafy grove in Western Australia, this salt lake rose from the ground when the nearby woodlands were cleared for farms. Thirsty trees had absorbed rainwater and kept the water table from rising, but after they were cut, the water surfaced and brought salt with it. The result: saline ponds and dead fields".

The following table (Table 14) is taken from a CSIRO guide for selecting trees native to Australia. The tree size would have over lapping ranges. Shrubs and small trees may be considered to be less than ten meters (33 feet) in height, medium trees 10 – 30 meters (33-99 ft.) and tall or large trees more than thirty meters (99 feet) height at maturity. The frost tolerance is not clear in the guide, perhaps one reason would be that Australian winter temperature does not appear to be as cold as North American temperature. The most tolerant seem to tolerate conditions only a few degrees below 0°C (32°F). The most frost tolerant trees appear to be the least salt tolerant.

Table 14: Taken from CSIRO guide for selecting trees native to Australia

Scientific name	**Common name**	**Size**	**Salt tolerance +**	**Frost tolerance**
Acacia ampliceps	Salt wattle	Small	10-15 : 20	Intolerant
A. cyclops	West coast wattle	Shrub	10-15 : 20	-3 °C
A. melanoxylon	Swamp blackwood	Tall	5 : 5	-9 °C
A. salicina	Willow wattle	Small	10 : 15	-5 °C
A. saligna	Orange wattle	Shrub	5 : 10	-4 °C
A. stenophylla	River cooba	Small	10-15:15-20	-4 °C
Casuarina cristata	Belah	Tall	10 : 15	-5 °C
C. cunninghamiana	River sheoak	Tall	5-10 : 10	-8 °C
C. glauca	Swamp sheoak	Medium	10-15 : 15	-4 °C
C. obesa	Swampy oak	Small	10-15 : 20	-3 °C
Eucalyptus aggregata	Black gum	Small	0-5 : 5	-8 °C
E. botryoides	Southern mahogany	Tall	0-5 : 5	-8 °C
E. brockwayi	Dundas mahogany	Medium	0-5 : 5	-3 °C
E. camaldulensis	River red gum	Tall	0-5 : 10-15	-6 °C
E. camphora	Swamp gum	Small	0-5 : 5	-9 °C
E. cladocalyx	Sugar gum	Small	0-5 : 5-10	-4 °C
E. globulus	Southern blue gum	Large	0-5 : 5-10	-4 °C
E. grandis	Rose gum	Tall	0-5 : 5-10	Sensitive
E. kondininensis	Kondinin blackbutt	Medium	15-20: 20	-3 °C
E. largiflorens	Black box	Medium	5-10 : 10	-6 °C
E. leucoxylon	Yellow gum	Medium	5-10 : 10	-5°C
E. occidentalis	Flat-topped yate	Medium	10 : 15-20	-4 °C
E. robusta	Swamp mahogany	Large	5-10 : 10	-6 °C
E. sargentii	Salt river gum	Small	10-15 : 20	-3 °C
E. spathulata	Swamp mallet	Shrub	10-15 : 15	-4 °C
E. tereticornis	Forest red gum	Tall	5-10 : 10-15	-6 °C
Melaleuca halmaturorum	Swamp paperbark	Shrub	10-15 : 20	-5 °C
M. leucadendra	Long leaved paperbark	Tall	10-15 : 15	Intolerant
M. linarilfolia	Narrow leaved tea	Shrub	5-10 : 10	-6 °C
M. quinguenervia	Broad leaved tea	Small	5-10 : 15	Sensitive

+ The salt tolerance is listed as ECe in dS/m. The first set of terms indicated the soil salinity conditions when growth is reduced. The second set of numbers (after the colon) indicated salinity conditions at which tree mortality begins. From : Marcar, N., D. Crawford, P. Leppert, T. Jovanovic, R. Floyd and R. Farrow, 1995 Trees for saltland: a guide to selecting native species for Australia. CISRO Australia.

The guideline is set up to recommend plantings where salinity has already affected the soil conditions. The Australian reader would intend to plant the trees into those conditions and then irrigate if necessary to establish the trees. The guide does not appear to have the intent of actually irrigating the trees with water that has high salinities. For conditions in the San Joaquin Valley of California only the most frost tolerant should be selected. If the user intends to irrigate with saline drainage water, then only the most tolerant (i.e. those that can tolerate EC_e = 15 –20+ dS/m prior to the onset of mortality).

One should not select trees based upon this table alone. If plans are being made for irrigation with drainage water, one should also consider the trees ability to withstand water logging. The common names can help here, if they are called "swamp" or "river" it is often for good reason. A tree, which can tolerate moderate salt and water logging, will often succumb to the combination of both. *Eucalyptus camaldulensis* is an example of this. Research has shown that it can withstand months of flooded soil as long as the water is non-saline. The combination of saline water and poor aeration is fatal.

Another problem is that some trees can tolerate saline soils under acid or neutral soil chemistry. *Casuarina cristata* and *cunninghamiana* become chlorotic when grown on calcareous soils.

The guide book lists other species of the *Acacia, Allocasuarina Eucalyptus* and *Melaleuca* that are slightly to moderately salt tolerant and may be useful in salt affected soils, but does not provide the detail necessary to include them in the above table. It also lists a few *Eucalyptus* species that show some promise in Western Australia, but do not have enough research to make recommendations.

The only two Australian non-native tree species discussed in the CISRO document were *Populus euphratica*, which is only moderately salt tolerant and *Tamarix aphylla* (athel), which was not recommended due to its habit of dripping salt onto the soil surface.

Cervinka and others have tried various species of trees for agroforestry. Among those tried in the SJV were *Eucalyptus camaldulensis, E. gomphacephala, E. trabuti, E. rudis, Populus sp, Casuarina glauca, C. cumminghamiana, Tamarix aphylla* (athel), *Mesquite* (Cervinka et al. 1999). Various hybrid clones of both *Populus* and *Eucalyptus* were also grown and or tried in greenhouse salinity trials. (Shannon et al., 1998) Accumulated research for each of these genera will be presented in the following pages of this report. Some consideration will be given to the history of the selection for salt tolerance, water logging or flooding, and frost tolerance. Economic considerations for each will also be considered.

As indicated above it is sometimes difficult to separate the research into separate species, but an attempt will be made to do so for the remainder of this report. Some special comments by individuals are also provided in the appendix at the end of this document.

Eucalyptus

A very good review of the worldwide ecological effects of eucalyptus has been provided by Poore and Fries (1985). According to these authors there are over 600 species of eucalypts with some 80 countries having planted more than 4 million hectares outside the natural range of the species in Australia. This review contains a discussion on the water cycle as affected by water use and the effect of trees on soils, but does not provide information on the salt tolerance of the species.

There is no data in the usual handbooks such as Maas and Hoffman (1977), Maas and Grattan (1999); thus, one must find salt tolerance elsewhere in the scientific literature. Predominant salt tolerant studies on the species are available from Australia as presented in the introduction to this review, listing sixteen species of eucalyptus. Another table (Table 2) from Australia lists the salt and flood tolerance of twenty-two species.

Table 15: Salt and flood tolerance

Eucalypt Species	Salt Tolerance dS/m	Flood Tolerance
E. occidentalis	20 to 30	A
E. cornuta	10 to 20	B
E. incrassata	10 to 20	C
E. halophylia	10 to 20	C
E. platypus var. heterphylia	10 to 20	C
E. sargentii	10 to 20	C
E. spathulata	10 to 20	C
E. salicola	10 to 20	C
E. stricklandii	10 to 20	C
E. astringens	2 to 10	C
E. botryoides	2 to 10	B
E. camaldulensis	2 to 10	A
E. campaspe	2 to 10	C
E. diptera	2 to 10	C
E. diversifolia	2 to 10	C
E. gomphotephala	2 to 10	C
E. intertexta	2 to 10	B
E. kitsoniana	2 to 10	A
E. largiflorens	2 to 10	B
E. leucoyton	2 to 10	C
E. microtheca	2 to 10	B
E. porosa	2 to 10	C

Flood tolerance: A- can withstand flooding of a month or more.
B- can withstand flooding of less than one month.
C- must have a well drained soil – no flooding.

Source: www.vti.waite.adelaide.edu.au/agroforestry/salinity.htm

These two lists, Table 14 and Table 15, have only five species in common: *E. occidentalis, E. sargentii, E. spathulata, E. camaldulensis* and *E. largiflorens.* Comparing the above chart, Table 15, to the results of Donaldson et al., (1983) Table 16 shown below, from California one finds only seven species satisfactorily common to both lists. They are *E. occidentalis, E. cornuta, E. incrassata, E. sargentii, E. spathulata, E. camaldulensis* and *E. microtheca.* *E. platypus* was one of the twenty six species to survive in the Donaldson plots, but was judged to be "not acceptable". The point to be made is that only four species are common to all three lists, Table 14, Table 15 and Table 16.

Table 16: Eucalyptus grown in Napa County, CA On salty flooded soils (Donaldson et al. 1983).

Eucalyptus species	Notes	
E. bauerana	Surviving and Acceptable	o
E. bicolor	Surviving and Acceptable	f
E. camaldulensis var rostrada	Surviving and Acceptable	f
E. cornuta	Surviving and Acceptable	
E. cosmophylla	Surviving and Acceptable	
E. fruticetorum	Surviving and Acceptable	o
E. grossa	Surviving and Acceptable	o
E. incrassata	Surviving and Acceptable	
E. lansdowneana	Surviving and Acceptable	o
E. mellidora	Surviving and Acceptable	
E. microtheca	Surviving and Acceptable	
E. occidentalis	Surviving and Acceptable	
E. populifolia	Surviving and Acceptable	
E. rudis	Surviving and Acceptable	f
E. sargentii	Surviving and Acceptable	
E. spathulata	Surviving and Acceptable	
E. tetraptera	Surviving and Acceptable	
E. aggregata	Surviving, but not Acceptable	f
E. albens	Surviving, but not Acceptable	
E. anceps	Surviving, but not Acceptable	
E. blakelyi	Surviving, but not Acceptable	
E. burdettiana	Surviving, but not Acceptable	
E. eremophila	Surviving, but not Acceptable	
E. falcate	Surviving, but not Acceptable	
E. platypus	Surviving, but not Acceptable	
E. rugosa	Surviving, but not Acceptable	

o- planted for observation only donated by others
f- survived 1972 freeze as one-year old plants
It should also be noted that there were twenty-nine species not listed that were grown but did not survive the ten year period.

Other studies are (Pepper and Craig, 1986) who assessed the resistance of twelve species of Eucalyptus in Western Australia and found "the best survival, health and growth of species at high soil salinity was by *Eucalyptus occidentalis, E. sargentii,* and *E. platypus* var. *hetrophylla*. The most salt sensitive of the trees tested were *E. rudis, E. camaldulensis*, and *E. robusta*. At soil salinities greater than 10 dS/m *E. camaldulensis* had low survival and trees showed poor health an vigor. *E. robusta* died at soil salinities less than 7.5 dS/m."

Van der Moezel et al., (1988) found that *E camaldulensis* actually grows better under salt free, but water logged conditions than in a well-drained sand. Marcar (1993) found *E camaldulensis* performed significantly better than *E. globulus*, E. *robustus*, and *E. tetracornis* when subjected to the combination of salt and water logging. The salt content of the solution used in the Marcar study was in the range of 10-15 dS/m.

Choukr-Allah (1996) states, "*Eucalyptus occidentalis* and *E. sargentii* Maiden, useful landscape trees, can stand a salinity over 30 dS/m and there may be other equally tolerant species."

These studies would indicate that even though there are a great number of species of eucalyptus, there are only a few that are salt and flood tolerant. Even here there is some inconsistency in the data, but the results in other countries should provide an indication of the most saline and flood tolerant species for use in saline drainage water reuse experiments.

In the San Joaquin Valley of California, the main species used in the "agroforestry" plots was *Eucalyptus camaldulensis*. Cervinka states that his selection of *E. camaldulensis* is based upon "its high salt tolerance"; he goes on to say, "the seeds were obtained from the areas of Lake Albucutya and Alice Springs in Australia" (Cervinka, 1987).

Sachs et al. (1990) performed some of the early California salinity screening and reported that seeds harvested from eucalyptus trees on the Gowan Ranch interceptor line and screened with saline water EC 10-12 dS/m and 15 ppm boron, showed superior salt tolerance than the Australian seedlings brought by Cervinka. For all trees, even the best seedlings, growth was reduced 50-70% over controls grown in non-saline nutrient solutions used as controls. The *Eucalyptus camaldulensis* seedlings from Lake Albucutya had 80-90% failure under saline conditions due to severe phytotoxicity and lack of stem elongation. Seedlings from Lake Coorong, also in Australia, had 70% failure rates. Some clones of *E. camaldulensis* that may have been selected earlier from these provenances showed no phytotoxic symptoms, but did have significantly reduced growth rates.

Other eucalyptus species tested by Sachs et al. (1990) were *E. australiana, E. mannifera, E. gomphocephala, E. polybactea, E. largiflorens* and *E. leucoxylon*. All were able to tolerate and grow in saline irrigations waters of 4-5 dS/m except *E. australiana*, which had damaged seedlings and a 50% reduction in growth at this salinity. There was a 100% death rate for *E. australiana* grown in irrigation waters of EC = 10-12 dS/m. The *E. leucoxylon* was judged to be the most salt tolerant of this group. As noted above all species had 50-70% reduction in growth when the irrigation water with stronger salinities was used. The water use by *E. gomphocephala* was estimated to be 50% of those plants grown under non-saline conditions.

Jorgensen et al. (1993) provide data on the Mendota site stating that the irrigation water used was from a portion of the Westlands Water District Drain. The average values were EC = 10 dS/m, 12 mg/l boron, 400 mg/l selenium and SAR = 11. This water was put on 9.43 ha of *E. camaldulensis* starting in 1987. From 1987 – 1989, the water was applied when farm labor was available, not on any regular or scientific basis. Jorgensen stated that this met neither the tree needs nor the leaching requirement during this period. Soil ECe levels climbed to 30 dS/m averaged over the top 2.4 meters of soil profile. Beginning in the 1990 season water was applied to meet the ET requirements of the trees plus a 16% leaching requirement. The salinity levels ECe, declined to 18 dS/m by June 1991 and to 10 dS/m by 1998. Trees were harvested in the summer of 1992 and sold as chips. Part of the plantation was then planted with superior eucalyptus clones selected since the first planting. The remainder was to be studied for regrowth rates. (Information on this is also included in the history of the Mendota site.)

Selection of clones:

Eucalyptus camaldulensis has been shown to have considerable genetic diversity and individuals of this species hybridize with other Eucalypt species. Thomson et al. (1988) conducted an evaluation of 53 seed sources from the natural range of *E. camaldulensis* and determined the mean salinity causing mortality ranged from 358 to 636 mM NaCl (32.4 – 57.6 dS/m). Trees derived from the initial uniform seedlings may show a 2 to 3 fold difference in growth rate in the field. Using this genetic diversity *E. camaldulensis* clones have been developed and tested for tolerance to salinity in the SJV (Sachs and Cartwright, 1989; Grieve et al., 1999; Grattan et al., 1996a, 1996b, 1996c, 1997).

After the 1990-91 freeze *Eucalyptus camaldulensis* clones were selected by Vashek Cerevinka, CA Dept. Food and Agriculture and Frank Menezes USDA-NRCS, Fresno, CA. These selections were based upon consultation with collaborators from the plots planted in the 1980's (See Case Studies portion of this report). M. Shannon and C. Grieve selected the following clones for further testing based upon observations taken during a field trip to the SJV on April 24 & 25, 1995: Clones 4501, 4543, 4544,4573, 4590 (Twyford Plant Labs, Santa Paula, CA), clones 2007 and 2016 (NyPA Inc., Tucson, AZ) and clone 2002 (Roy Sachs). The source of the clones is shown inside parentheses. These clones were then tested for salt tolerance using sulfate dominated irrigation water in the greenhouse at the Salinity Laboratory in Riverside, California.

Grieve and Shannon (1999) reported on the screening of four *Eucalyptus camaldulensis* clones 4543, 4544, 4573 and 4590, along with a clone of *E. rudis* with the designation 4501 for San Joaquin Valley salinity tolerances. Salinities ranged from 2 to 28 dS/m and greenhouse treatments were replicated three times. All plants survived and were harvested after seven weeks. Measurements of plant height were taken weekly and the plant biomass was determined at harvest. The salinities for which there was a 50% biomass reduction were 16.4 for 4573, 17.1 for 4543, 17.7 for 4544, 29.0 for 4590 and 30.0 for 4501. The clones easily fall into two categorical groups for salt tolerance. Over the range of salinities 4 – 20 dS/m clones 4573, 4590 and 4501 maintained higher relative growth rates (RGR) than 4543 and 4544; however, at the highest salinity 4544 had significantly higher RGR than those of clones 4543 and 4590.

Grattan et al. (1997) report, "Results from the short-term study that screened the salt-tolerance of different clones of *Eucalyptus camaldulensis* indicate that the salt-tolerance within this species is rather variable." The response of clone 4544 was mostly linear. According to the guidelines of Ayers and Westcot, (1985), the species falls within the moderately tolerant range, but a direct classification is difficult due to the nature of the experiment. There was a linear relationship between tree height and stem girth, but the slope changed with the growth of the trees. High levels of salinity reduced tree height and the 28 dS/M treatment affected the trees immediately after salinity was imposed. With the highest salinity, evapotranspiration was only half the level of the non-salinized nutrient solution.

High salinity did seem to have a great influence on the toxic affects of Boron. B toxicity was apparent on the leaf margins when high Boron was present with low salinity, but this evidence was reduced at the higher salinity levels.

Also an elaborate sand tank facility has been constructed at the USDA-ARS Salinity Laboratory on the UC Riverside campus. Two eucalyptus saplings (clone 4544) were transplanted into each tank on June 17, 1994. Salinity treatments were imposed after the trees reached 2m in height. One tree was harvested after one year (see 1995-96 report) to make a detailed analysis of treatment effect on growth and mineral and biomass partitioning within the shoot. Growth and biomass data were used to develop allometric relationships to accurately estimate plant foliar biomass based upon trunk and branch diameters for subsequent studies. The second tree remained in the tank to develop detailed information on water consumption, biomass production, water relations and long-term tree performance.

Grattan et al. (1996c; 1997) reported the data indicated that the threshold salinity was approximately 8 dS/m and 50% yield loss occurred at approximately the 22 dS/m treatment. Boron at 25 mg/L decreased the yields significantly for the non-saline treatments, but had no effect when the saline treatments were 22 dS/m or higher.

TLDD Project

At the Drainage Water Reuse Facility, about 25 miles South of Corcoran, CA a project sponsored by the U.S. Bureau of Reclamation was started with tree planting in October, 1994 (Oster et al., 1999b). The site is owned and operated by the Tulare Lake Drainage District. Three varieties of clonal Eucalyptus trees were planted in three 5.6 acre checks at a 14 foot row spacing and 6 feet in-row spacing (520 trees/ac). Irrigation with saline/sodic drainage water (EC 8.5 dS/m; SAR 33.4) began in 1996.

The hypothesis tested was that fall applied gypsum or a combination of fall applied gypsum and ripping would maintain or restore adequate soil physical properties for tree growth. The results demonstrated that gypsum was essential to maintaining good tree growth due to beneficial impacts on water infiltration and soil aeration in the winter and spring.

Growth rates in the trees were negligible until the fall of 1996. Average wood yields were measured in 1998 in cords per acre. Total yields for plots treated with gypsum (1.33) were significantly higher than the plots which had been treated with ripping alone (0.61), or by ripping plus gypsum application (0.75). Irrigation water was measured and rainfall was estimated from a nearby weather station. The average total applied water was 39.5 inches. The leaching fraction was 0.23; consequently the average annual amount used by the crop was about 30 inches. This does not provide the anticipated benefit of the consumption of drainage water by the agroforestry project.
In the above experiment, clonal lines differed. Only 57% of clonal line 4544 survived the first year. Percentage survival rates for clonal lines 4573 and 4543 were 73% and 75% respectively.

Based upon measurement of oxygen diffusion rates this was the first field study that conclusively shows poor soil aeration reduces the growth and productivity of eucalyptus.

Evapotranspiration:

Originally, one of the reasons for the selection of *Eucalyptus camaldulensis* was based upon its high rate of evapotranspiration(ET) and rapid growth rates (Donaldson, et al., 1983). If the growth and ET rates were lowered by saline environments, then reasons for the original selection may have been premature. Dong et al. (1992) reported on a 9.4 ha site in Mendota, CA that even though the literature showed crop coefficients (Kc) for full cover non-stessed *Eucalyptus camaldulensis* was 1.2 or higher, the highest reading at Mendota was Kc=0.83. There are other indications in the literature that ET for trees under salt stress may be only 80% or less that of unstressed trees (Poore and Fries,1985). Dong attributed this reduction in ET to salinity stress in the soil and possible boron toxicity.

Eucalyptus Economics

Sadorsky, P. et al, (1992-93) show that existing prices for bone-dry eucalyptus wood may not provide economic benefits to the farmer. The analysis was based upon the wood selling at $120 per bdt (bone dry ton) even though the highest actual price was for firewood in LA selling for $107/bdt. At these optimal conditions using unblended drainage water for a sixteen-year period the annualized net present value (ANPV) was only $62.62. Use of more expensive irrigation water to blend with the drainage water made the ANPV become negative. Subsequent analysis by the same authors (1992-93) determined improved ANPV by including the benefits of disposing of the drainage water, but this analysis was still based upon eucalyptus wood selling at higher prices than presently exist in California.

At the TLDD site Oster et al. (1999b) made the following assessment: "Assuming the linearity of production measured for two years, yields were projected through the year 2003. Assuming one tree of six being harvested each year, the highest projected annual wood yields would be 0.20 cords/ac in 1998 and 0.77 cords/ac in 2003. Based upon the price of firewood at the TLDD site ($30 - $50 per cord) the project would not generate enough income to offset the annual operating costs of $137.50 per acre or a share of the development cost of $1180/ac. Analysis indicates that the tree/ evaporation pond option is about 1.8 times more expensive than the evaporation pond option alone."

Casuarina

Casuarina species have gained recognition as useful trees to be planted in stressful environments. In China, *C. equisetifolia* has been planted on coastal sand dunes subject to infertility and salt spray (Turnbull, 1983). *C. glauca* and *C. cunninghamiana* have also been planted outside their native habitat, Australia. In the United States they have been judged useful for stabilizing sand dunes, eroded landscapes, reclaiming partially water logged soils (both fresh and brackish), and are useful as shade trees, windbreaks, and shelterbelts. They have been judged as a source of high quality fuel wood. In addition, they have the ability to fix nitrogen in the soil.

In California *Casuarina* has been successfully planted for windbreaks and fuelwood. Between 1987 and 1989 provenance trials were made on *C. cunninghamiana* and *C. glauca*. Some of the trial sites included salt affected lands in the San Joaquin Valley. (Miles, 1990)

Casuarina obesa, C. equisetifolia, C. cunninghamiana and *C. glauca* have been grown on various drainage water reuse (agroforestry) plots in the San Joaquin Valley (Cervinka et al., 1999). They have been irrigated with saline drainage water ranging from 6 to 20 dS/m. *C. glauca* is not frost tolerant; it was damaged by frost in 1990 and did not recover. *C. cunninghamiana* was frost damaged and did recover, but not as well as the eucalyptus species being tested (Cervinka et al., 1999). In January 2001, Cervinka verbally stated that all Casuarina were deemed not suitable for this use mainly due to their inability to survive and prosper in the SJV. Records from 1990-91 indicate that some provenances of this species did survive the freezing temperatures encountered, particularly when they had been irrigated sufficiently prior to the cold weather.

The only screening of this species for salt tolerance and water logging has been found in Australia (El-Lakany and Luard, 1983; Van der Moezel et.al., 1989). El-Lakany and Luard, (1983) found that *C. glauca, C. equisetifolia* and *C. obesa* were the most tolerant. Van der Moezel et.al., (1989) tested five species in a glasshouse for twelve weeks and found all species could tolerate water logging due to the aerenchyma in the roots. *C. obesa* and *C. glauca* were the best species tolerant of both salt levels (NaCl) up to 56 dS/m and water logging. It should be noted that relative growth was decreased to 20-35% of the control in the *C. glauca* and to 40-60% of control in the *C. obesa*. *C. equisetifolia, C. cristata* and *C. cunninghamiana* had few seedlings survive the full twelve week period of testing. However, it should be noted that the onset of these seedling deaths did not begin until salt levels reached 49 dS/m.

Van der Mosezel et al., (1988) has also compared the growth of C. obesa and six species of eucalyptus when exposed to water logging and salt. The experiment compared the species with a control of nutrient solution in well-drained sand, water logged sand, salt added to nutrient and well drained and finally combined salt and water logging. With water logging alone, the *Eucalyptus camaldulensis* actually grew better than control. When salt was added growth ceased for the eucalyptus. Saline and freely drained conditions actually killed the E. kondininensis outright, whereas the others at least survived. Under the combined stress of water logging and salt all the eucalyptus species died during the experiment.

For a time, examination of aerial photos at TLDD seemed to indicate that *C. obesa* and *C. glauca* were performing better than all other trees. However, D. Davis (personal communication 2001) indicated that these trees were brought back to health by irrigation with non-saline water. They are once again being irrigated with saline drainage water of about 8 dS/m and growth rates have declined. At the TLDD site casuarina do seem to have better survival rates than the eucalypts.

Chhabra (1996) reports that *C. equistifolia* grown on soils with a pH of 9.5 to 10 and ESP of 25-50 had high performance. However, others from India (Tomar and Patil, 1998) report that *C. equistifolia* and the eucalypts did not perform as well as A*cacia nilotica* and *Prosopis juliflora* under saline conditions.

Pasternak and Nerd (1996) report that *Casuarina glauca* and *Casuarina stricta*[10] were able to grow successfully in 100% seawater in experimental plots at Asquelon.

[10] Casuarina stricta has apparently been renamed *Allocasurina verticillata* (Lam.) (drooping sheoak). The Australian book, Trees for the saltland, states that it tolerates wind, frost, drought, water logging and moderate salinity.

Tamarix

Another salt tolerant plant grown in the Agroforestry plantations of the San Joaquin valley was Athel (*Tamarix aphyllà*). Athel is a large evergreen tree growing to about 40 feet and is reported to be less weedy than other tamarix species. Eight species of *Tamarix* have been introduced into North America primarily as ornamental trees and shrubs for windbreaks and shade. In addition to athel, the species found in the southwest are *T. chinensis, T. parviflora, T. ramosissima* and *T. gallica* (DiTomaso, 1996). Salt-cedar are faculative phreatophytes (deep rooted to reach the water table); hence, they may be ideal as "vertical pumps". Johnson (1986) reported that a million acres of Tamarisk uses more water than all the communities in southern California.

Tamarix do well under a variety of stress conditions, including heat, cold, drought, flood and high concentrations of dissolved solids. They survive lengthy drought by dropping their leaves and mature plants have been known to survive complete submergence for a period of seventy days (Kerpez and Smith, 1987). *Tamarix* is not an obligate halophyte, but have been known to survive in groundwater where the concentration of dissolved solid approaches 15,000 ppm (Carman and Brotherson, 1982). The species exudes excess salt crystals from openings in its leaves (Neill, 1985). Salt concentration has been reported as high as 41,000 ppm in this guttation sap. Salt accumulates on the soil surface, combining with needles to serve as an allopathic barrier preventing the germination of most other species. In some communities salt grass (Distichlis spicata) serves as the understory (Brotherson and Winkel, 1986).

The major drawback to *Tamarix* species as agroforestry or drainage water reuse plants in the San Joaquin Valley is their reputation for spreading and tapping into limited water supplies in the desert. They crowd out native streamside and wetland communities. John Diener, owner of an agroforestry plantation in the San Joaquin Valley, has stated that athel tend to obstruct tile lines very aggressively. In California much more effort is presently being expended on clearing *Tamarix* and restoration of the areas it has invaded (Johnson, 1986; Egan, 1996). Indeed an entire workshop was devoted to "Salt Cedar Management and Riparian Restoration" in 1996. Athel (*T. aphylla*) is apparently not as invasive as its more shrublike relatives, *T. chinensis*, because its seeds are not viable after a few weeks. It requires warm moist salt free soils to germinate and may not spread into cropland areas. However, the biological controls being studied and released to control the more weedy salt cedars could adversely affect the tree and its own salt releasing allopathic properties could harm other plants in an agroforestry plantation.

Cervinka has stated that Athel recovers well from frost damage and that they may be benefical when the salt concentration is greater than EC = 20dS/m (Cervinka et al., 1999.) Australian papers have reported its salt tolerance for the range EC = 20 to 30 dS/m and have stated that it can survive a month of flooded conditions.

Horton, (1977) reports that the aggressive *Tamarix* is *T.chinensis* Lour. He states that it does not perform well when the water table is less than five feet or more than twenty feet in depth. When the water table is less than five feet saltgrass (*Distichlis* *stricata)* and Bermuda grass (*Cynodon dactylon* L. Pers.) compete well for the moisture, but when the water table drops below five feet the *Tamarix* grow dramatically and shades out the grasses. If the water table drops below twenty feet in *Tamarix,* a large portion of the shrubs will be killed.

Water use was found to decrease from 300 cm/yr to 100 cm/yr as EC of the irrigation water was increased from 10 to 40 dS/m at 25 °C (Van Hylckama, 1970). Since one of the main reasons for the irrigation of trees with saline is to dispose of the excess, this decrease in ET would indicate that substantially larger acreages of tamarisk would be required.

Tamarix are used for furniture in the Middle East, but have no economic use in the United States. The high salt content makes it a poor source of firewood.

Prosopis (Mesquite)

Considerable work has been accomplished determining the salinity tolerance of *Prosopis* species utilizing sand culture pot experiments. The species tested were: *P. glandulosa* var. *torreyana P. velutina; P. articulata; P. chilensis; P. pallida* and *P. tamarugo* (Felker et al. 1981). All were able to tolerate 6000 mg/L (EC 7.3 dS/m) salinity with no reduction in growth. *P. velutina* was the only species that poorly tolerated 12,000 mg/L (EC 13.0 dS/m). *P. articulata, P. pallida* and *P. tamarugo* grew in 18,000 mg/L (19.6 dS/m) saline solution and grew slightly in 36,000 mg/L (39.1 dS/m). *P. articulata* had the best biomass production at high saline levels producing 169g compared to 380g with the control. It should also be noted that the *P. glandulosa* had biomass reduction from 332g in control to 54 g at the highest salinity levels and *P. tamarugo* had only 1.9g of biomass with the control. These were the first legumes known to tolerate and grow in salinities as high as seawater, but as noted from the low weights are very small plants. Maas and Grattan (1999) list *Prosopis tamarugo* as tolerant, but no other *Prosopis* are listed in the tables of plants tolerant of salinity.

Adams et al. (1979) provided salt tolerance of *Prosopis* species, based upon trials in Kuwait, as follows:

P. juliflora aka. *glandulosa*	50 dS/m
P. tamarugo	35 dS/m
P. juliflora var. *velutinus*	30 dS/m
P. chilensis and P.velutina	16 dS/m

Among the salt tolerant trees selected for growing in the Negev Desert in Israel are *Prosopis alba, P. juliflora* and *P. nigra* (Pasternak and Nerd, 1996). No data are provided as to the tolerance of these trees or the salinity of the soil in which they were grown. The same authors report that *P. nigra* and *P. pallida* were grown near Ashquelon using full strengh seawater (54 dS/m) and 15% seawater (9 dS/m), but results of these plantations were not clearly reported for the Prosopis species.

Prosopis tamarugo is described as a very salt tolerant South American native tree planted in Chile for livestock. Seed pods and forage are harvested from the tree. It has relatively slow growth until well established. *P. chilensis* is also a South American tree planted for animal feed in arid regions. It grows to fifty feet in height, is thornless, and was the best biomass producer in University of California-Riverside trials. *P. alba* is a valuable South American fuelwood tree, that can also be used for windbreaks, fodder, timber and ornamental purposes. It is said to be only moderately salt tolerant in UCR trials (Virgina et al., no date).

P. velutina is a native tree of Arizona. In trials at Brawley, CA it was found to be a good producer of seed pods. It is said to have come from rainfed upland regions where salinity is not a problem. *P. pallida* and *P. articulata* occur along the arid coastal regions of Hawaii and Baja California, where groundwater probably mixes with seawater. The drawback of *P. articulata, P. pallida* and *P. tamarugo* was they did not seem to be as frost tolerant as other species (Felker et al., 1981). Felker et al.(1983) reported that *P.*

pallida, P. juliflora and *P. africana* were killed by –5 °C temperatures at Riverside, California in the winter of 1978-79.

Economics of ***Prosopis***

Felker (1984) stated that mesquite producing 7 dry tons per acre per year should be able to economically produce a sustainable forest which would generate power at a 500 Mwatt facility as long as haul distances were not greater than 15 miles. He also stated that it has been shown that mesquite can produce up to 6.3 dry tons per acre. Thus, due to the short haul distance and the fact that Prosopis does not produce the required tonnage it should be understandable that wood production for power generation by this species is not economical. The salt tolerance information Felker et al.(1981) provide show a decrease in biomass production when the trees are irrigated with saline waters.

In another study (Felker et al., 1983) reported that *P. chilensis* had the highest biomass production on irrigated plots at Riverside, California producing the above mentioned figure of 6.3 dry tons per acre per year for a period of 2½ years after planting. The worst accessions produced only 1/20 the biomass of *P. chilensis*. The driest plots of the species had water use efficiencies of 345 parts water to 1 part biomass. Felker compares this with domesticated legumes that have efficiencies in the range of 500 to 900 and produce comparable tonnage of dry matter. They believe the nitrogen fixing abilities of the trees, the use of pods for livestock feed and wood production would make *Prosopis* an economically feasible crop in arid regions, but have not produced convincing figures or demonstrated the potential.

Populus

Cervinka reported that he had grown native poplar, *Populus fremontii,* and hybrid poplars in various locations in the valley as part of his agroforestry program (Cervinka et al. 1999). His presentation did not provide any information as to the success or failure of this species as a plant for drainage water reuse. Donaldson et al., (1983) reported that *Populus euprhatica* survived but was not acceptable in his salty, flooded soils in the Napa Valley of California. Later, Donaldson reported that these plants originally from the Euphrates river delta region in Iraq had performed well and were still living at the experimental site in 1999. (Donaldson, personal communication)

Shannon et al. (1999) have reported on *Populus* species tested for salt tolerance at the Salinity Laboratory in Riverside, CA. They noted a significant variation among the clones, but the salinities for which the dry weight (i.e. growth) was reduced ranged from 3.3 to 7.6 dS/m. These writers have concluded that the *Populus* hybrids tested were significantly less salt tolerant than eucalyptus (Shannon et al., 1999). The known parent species used in this study were *Populus trichocarpa, P. deltoides,* and *P. nigra.* Based upon this experiment, if one had to grow hybrid poplars on saline soils a cross between *P. deltoides* and *P. nigra* known as hybrid DN-34 would be the most tolerant.

From the above range of salt tolerance one might easily conclude that it would be best to utilize the land and the drainwater to grow cotton than to attempt to plant the less economical hybrid poplar.

The species is used elsewhere in agroforestry programs utilizing municipal wastewater as the irrigation supply. It seems to serve well in this purpose but due to its relatively low salt tolerance is probably unsuitable for use with the drainage water in the San Joaquin Valley.

Acacia

Another nitrogen fixing plant, which could be considered for the Agroforestry plantations are the various acacia species. According to information from Australia *Acacia saligna* (golden wreath wattle) can tolerate 20-30 dS/m; *A. stenophylla,* also known as river cooba, is said to tolerate 10 to 20 dS/m and is adapted to heavy clay soils and semi-arid conditions; *A. salicinia,* (cooba) said to tolerate 2-10 dS/m saline growing conditions but tends to sucker and form thickets. Other Acacia species said to be saline tolerant are: *A. auriculiformis,* (black wattle), a tree said to grow a straight stem to 30 meters (100 ft) and provide good fuelwood, and *A. kourittii.*

Two species reported to do well in poorly drained soil are *A. pendula* Myall, a hardy slow growing shade tree to 60 feet, and *A. harpophylla* (Brigalow), a hardy farm tree to 66 feet good for windbreaks. Both are also drought and frost resistant, but no information was provided on the tolerance of saline conditions.

A. stenophylla has been used under saline soil conditions in Pakistan. *A. nilotica* has been used in India.

Sachs reported planting *Acacia saligna* at several sites in the San Joaquin Valley (Sachs, 1990). This writer has been unable to find information regarding the species or it performance. One apparent problem with using *Acacia* in the SJV is its inability to withstand freezing temperatures.

Eldarica Pine

When the Mendota agroforestry demonstration plot was started in 1985 it was reported that 72 Eldarica pine were planted in July. Cervinka reported (personal communication) that all pine trees planted at the Mendota did not survive the saline drainage water irrigations.

Pinus eldarica (perhaps also related to *P. brutia,* Calabrian pine and *P. halepensis,* Allepo pine) is a species native to the Caucasus region and is said to be drought and salt tolerant. In the native region they grow between 200 and 600 meters elevation and in an area receiving from 10 to 14 inches (250-350 mm) of total rainfall. The mean summer temperature is about 30 degrees Centigrade and they are subjected to freezing in the winter months. These are similar to many conditions in western North America (Mirov, 1967). Komarov (1934) described the native area as alkaline and poor in nutrients. It has been planted in a broad region from Iran to Pakistan.

Introductions to the arid mountains of North America have exhibited remarkable growth and survival characteristics beyond any native pines when grown in conditions of high temperature and low rainfall, such as Arizona and New Mexico. In 1972-75 the state of Arizona obtained seeds from Quetta, Pakistan and distributed them throughout the state. They were found to tolerate summer temperatures, between 40 and 45 degrees Centigrade, and in 1976 survived three consecutive nights with lows of –15 degrees at an altitude of about 5000 feet in north central Arizona.

Much of this information was obtained from an undated, unpublished draft apparently presented as a proposal for provenance testing.